Reduction of Grain Loss During Harvesting Due to the Rational Distribution of Vehicles

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Abstract. The paper deals with the mathematical model of the rational distribution of vehicles, which allows attaching them to a group of combine harvesters during harvesting, depending on the carrying capacity of vehicles, the productivity of combine harvesters and the capacity of grain storage facilities. In addition, it presents a formula which allows determining the required number of vehicles that will deliver grain from a group of combine harvesters. Further the article presents calculations of routes of vehicles movement and determination of the required number of vehicles de-pending on the carrying capacity of one of the operating agricultural organizations.

1 Introduction

The qualitative and timely harvesting of grain crops is one of the most important factors for increasing the food potential of Russia. In the process of harvesting, vehicles transport up to 95%, and in many regions 100% of the harvested crop from the fields. The short harvesting time, as well as the unsatisfactory condition and insufficient number of trucks, leads to a loss of grain. So, in 2016, in the Oryol region as a result of the above causes and weather-climatic conditions, grain losses accounted for up to 30% of harvested crops.

The role of motor transport in the process of harvesting cannot be limited only by the delivery of grain from the field to the granary. It plays a key role in the formation of harvesting and transport links, as well as due to the rapid delivery of grain to the granary, it allows achieving quality and safety of grain. Thus, one of the primary tasks of the organization of the harvesting and transport process is to increase the efficiency of the use of motor vehicles [1].

The solution to the problem of increasing the efficiency of the use of vehicles, the safety of the harvested grain and bringing it to the marketplace during harvesting is achieved as a result of the application of mathematical models that take into account the carrying capacity of vehicles, the productivity of combine harvesters and the throughput of grain storage facilities [15].

When transporting grain from a combine harvester to a grain storage facility, two tasks must be solved:

- to determine the volume of grain transportation along the routes;
- to calculate the need for road transport by carrying capacity and transportation routes.

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2 Material and methods

The basis of the developed mathematical model is the class of dynamic streaming models, called the “Integer production-transport model”, which is a modification of the production-transport model [2]. The advantage of the developed model is that it considers the process of production and transportation of grain as a whole, and also offers a solution to the task in view of the productivity of vehicles and combine harvesters. In addition, this model takes into account the significance of grain losses from untimely harvesting, since the mass of losses, reaching 30% of the harvested crop, is one of the key factors in reducing production costs and increasing the volume of harvested crops.

3 Theory

The choice of the optimal variant of the volumes of harvesting and distribution of transport flows is set as the task of minimizing costs: [3-14]

$$\left(\sum_{i=1}^{n}\sum_{r=1}^{R_i}\left(c_{ir}z_{ir}+\sum_{e=1}^{d}Q_{eir}\delta_{ei}c_e\right)+\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{K}t_{ijk}x_{ijk}\right)\Rightarrow \min \tag{1}$$

$$\sum_{r=1}^{R_i}a_{ijr}z_{ir}-\sum_{k=1}^{K}x_{ijk}\geq 0,\quad i=1,...,n;\ j=1,...,m; \tag{2}$$

$$\sum_{r=1}^{R_i}z_{ir}\leq 1,\quad i=1,...,n; \tag{3}$$

$$\sum_{i=1}^{n}x_{ijk}\geq b_{ik},\quad k=1,...,K;\ j=1,...,m; \tag{4}$$

$$x_{ijk}\geq 0,\quad i=1,...,n;\ j=1,...,m;\ k=1,...,K; \tag{5}$$

where: the cost of harvesting grain on the r-th option on the i-th field:

$$\sum_{i=1}^{n}\sum_{r=1}^{R_i}c_{ir}z_{ir}\ ,$$

the cost of losses of unharvested grain volume on the i-th field for the r-th harvest option:

$$\sum_{e=1}^{d}Q_{eir}\delta_{ei}c_e\ ,$$

costs for transportation of agricultural crops of the j-th kind from the i-th field to the k-th point of consumption:

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{K}t_{ijk}x_{ijk}\ ,$$

j is a type of crop ($j = 1,...,m$);
k is a point of consumption of agricultural crops ($k = 1,...,K$);
i is a field which is harvested ($i = 1,...,n$);
r *is* a field harvesting option ($r = 1,\ ...,\ R_i$; $i = 1\ ,...,\ n$);
c_{ir} are total costs (gross cost) associated with harvesting the agricultural crop on the r-th option on the i-th field;

z_{ir} *is* the required intensity of using the r-th harvest option on the i-th field, with $z_{ir} \epsilon \{0; 1\}$. If the solution $z_{ir} = 1$, then the option is included in the optimal plan, and $z_{ir} = 0$ means that it is not included. At the same time, for each object, no more than one option can be used;

Q_{eir} is unharvested grain volume on the *i*-th field with the r-th harvest option;

∂_{ei} is the shortage of crop in shares on the *i*-th field;

c_e is the cost per unit of grain mass;

d is the number of days after agroterms;

t_{ijk} is the cost of transporting the unit of mass of agricultural crops of the *j*-th type from the i-th field to the k-th point of consumption;

x_{ijk} is the required volume of transportation of agricultural crops of the *j*-th type from the i-th field to the k-th point of consumption;

a_{ijr} is the volume of production of the *j*-th type of culture according to the *r*-th option on the *i*-th field;

b_{jk} is the total demand for agricultural crops of the *j*-th type in the *k*-th point of consumption.

The statement of the problem for calculating the need for motor transport was formulated as follows: it is necessary to find the required number of vehicles that work as part of the harvesting and transport link, delivering grain from combine harvesters to a temporary storage point, while taking into account the technical characteristics of the combines and the carrying capacity of each model of the vehicle.

Calculation of the required number of vehicles for the transportation of grain from combines is made on the basis of equality of the total volume of threshed grain harvesters and the operational capabilities of vehicles.

The volume of grain harvested by a combine during the cycle of the motor vehicle movement is determined by the formula:

$$V_n = \frac{t_a^C \times 3,6 \times q_n \times k_q}{\gamma \times \eta_b \times (1+d)}, \tag{6}$$

where t_a^C is car cycle time, hour;

q_n is the carrying capacity of the combine, kg/s;

k_q is harvester capacity utilization rate, 0,8-1,0;

γ is grain density, t/m^3;

η_b is the adjustment factor of bunker use, 0,95-1,1;

d is the ratio of the mass of straw to the mass of the grain.

After that, knowing how much grain harvesters thresh during the cycle of the vehicle, we find a rational number of vehicles, according to the formula:

$$x_i = \frac{m_i \times m_\kappa}{m_1^2 + m_2^2 + \ldots + m_n^2}, \tag{7}$$

m_i is the carrying capacity of a calculated motor vehicle brand, ton;

m_k is a grain mass threshed by all harvesters working on the field, ton;

m_1, m_2, m_n is the carrying capacity of a motor vehicle of the corresponding brand, ton.

Thus, when planning the transportation process, first we find the amount of harvesting (the number of combine harvesters) and the transportation of grain for each route, then for each route we find the required number of vehicles.

Due to the insufficient number of harvesters and vehicles, a large number of crops are harvested after optimal agro-terms, which leads to large grain losses.

The loss of grain due to harvesting after agro-terms is calculated by the formula:

$$\Delta Q = \sum_{e=1}^{d} Q_e \times \delta_e \,, \tag{8}$$

where ΔQ is the shortage of grain on i day, ton;
Q_e is the `volume of grain which is not threshed, ton;
d is the day of harvesting grain after the days of the agro-terms;
δ_e is the crop loss factor.
Table 1 shows the average loss rate per day for the Central Chernozem zone.

Table 1. The value of the crop loss factor on days after the agro-term

Days after the agro-term	1	2	3	4	5	6	7	8
Shortage of the crop in shares	0.012	0.019	0.028	0.039	0.051	0.064	0.082	0.103

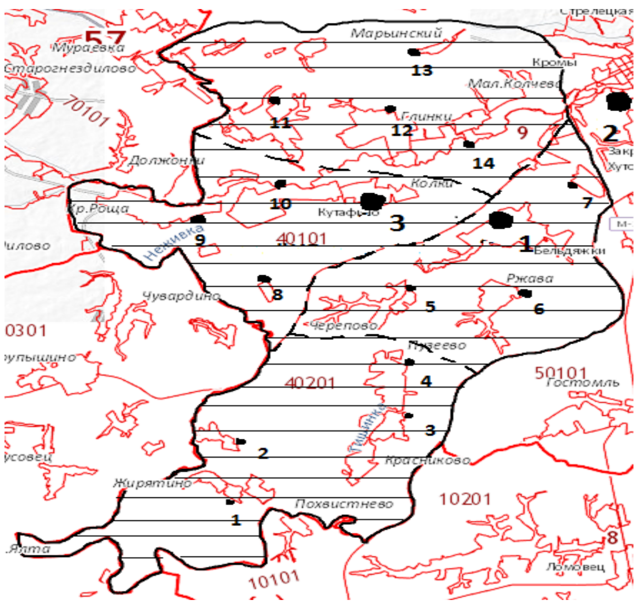

Fig. 1. Zoning of the territory and location of grain storage facilities.

Experimental studies were carried out in one of the advanced farms of the Oryol region, which has a large area of crops and occupies a leading position in the production of grain.

Since cereals are evenly distributed throughout the territory, zoning of the territory is necessary (Figure 1). That will allow to start harvesting all over the territory, to reduce the time and costs for moving grain harvesters to the harvested fields, to evenly load all existing grain storage facilities, and to harvest various crops as they mature.

In the course of the experiment, the task of minimizing costs and harvesting campaign was being solved, taking into account grain losses. In the framework of this experiment, the distribution of the number of harvesters over the fields was first carried out and the amount of harvested grain was assigned to temporary storage points. After that, a rational number of vehicles was found, for the transportation of grain from harvesters to temporary storage. At the final stage, the volume of grain located at temporary storage points by consumers was distributed.

4 Results and Discussion

Based on the data (Table 2), we will calculate for the first day of the harvesting campaign. Calculations for the following days will be made, based on this data, minus the results obtained for the previous day.

Table 2. Distance and costs for the delivery of grain from the harvesting area to the temporary storage location.

Harvesting area				Granary							
				1		2		3		4	
№	Area, hectares	Volume of harvesting, ton	Cost of harvesting, thousand roubles	Distance, km	Transportation costs, thousand ruobles	Distance, km	Transportation costs, thousand ruobles	Distance, km	Transportation costs, thousand ruobles	Distance, km	Transportation costs, thousand ruobles
A	232	876.9	58.00	19.8	173.63	22.1	193.81	6.3	55.25	9.2	80.68
B	217	809.4	54.25	2.7	21.85	11.3	91.46	18.1	146.50	23.8	192.64
C	186	682.6	46.50	12.9	88.06	3.7	25.26	16.4	111.95	18.1	123.55
D	198	766.2	49.50	23.8	182.37	19.7	150.95	4.5	34.48	1.7	13.03
E	207	755.5	51.75	13.3	100.49	6.3	47.59	7.1	53.64	9.6	72.53

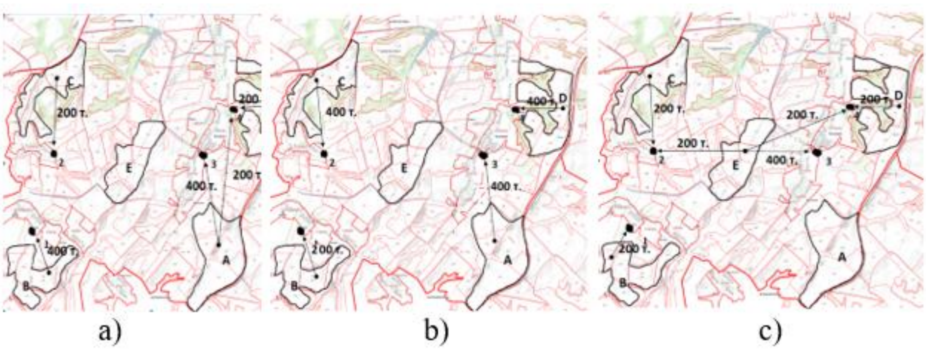

Fig. 2. Transportation scheme for harvested grain: a) on the first day of harvesting; b) on the second day of harvesting; c) the third day of harvesting.

After determining the volume of grain transportation, we find the required rational number of vehicles for each route of travel (figure 2, Tables 3-5).

Table 3. Required number of vehicles on the first day of harvesting.

Harvesting area	Granary	5 t.	8 t.	9 t.
A	3	2	-	1
A	4	1	-	1
B	1	1	-	1
C	2	1	-	-
D	4	1	-	-

Table 4. Required number of vehicles on the second harvesting day.

Harvesting area	Granary	5 t.	8 t.	9 t.
A	3	2	-	1
B	1	1	-	-
C	2	1	-	1
D	4	1	-	1

Table 5. Required number of vehicles on the third harvesting.

Harvesting area	Granary	5 t	8 t.	9 t.
B	1	1	-	-
C	2	1	-	-
D	4	1	-	-
E	2	1	-	1
E	3	2	-	1
E	4	1	-	1

5 The conclusion

Thus, it was possible to calculate the rational routes for the movement of vehicles, the required number of vehicles for transporting grain from harvesters to the granary. It led to the use of all available vehicles in the farm, reducing downtime of vehicles in anticipation of grain yielding by harvesters and idle time on the grain storage for grain unloading. Taking into account the bad natural and climatic conditions during harvesting, it helped to save up to 10% of the grown grain, unlike other farms.

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